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1 Attorney Docket No. 82759

2

3 APPARATUS FOR CHANGING THE ATTACK ANGLE OF A  
4 CAVITATOR ON A SUPERCAVITATING UNDERWATER RESEARCH MODEL

5

6 STATEMENT OF GOVERNMENT INTEREST

7 The invention described herein may be manufactured and  
8 used by or for the Government of the United States of  
9 America for governmental purposes without the payment of any  
10 royalties thereon or therefor.

11

12 BACKGROUND OF THE INVENTION

13 1. Field of the Invention

14 The present invention generally relates to an apparatus  
15 for changing the attack of a cavitator on a supercavitating  
16 underwater research model.

17 2. Description of the Prior Art

18 Supercavitating underwater vehicles and projectiles are  
19 known in the art. One such supercavitating underwater  
20 projectile is described in Harkins et al., U.S. Patent No.  
21 5,955,698. This projectile uses a supercavitating nose  
22 section that provides a cavitation bubble of sufficient size  
23 to encompass the body of the projectile which reduces  
24 hydrodynamic drag. The cavitating nose section described in  
25 the Harkins et al. is a fixed position cavitating nose

1 section and cannot be maneuvered so as to vary the angle of  
2 attack of the projectile. Brown et al., U.S. Patent No.  
3 5,929,370 discloses another underwater projectile having a  
4 fixed-position nose assembly.

5 The development of supercavitating underwater vehicles  
6 depends heavily upon supercavitating underwater research  
7 models. Typically, the supercavitating underwater research  
8 model is positioned in a large tow tank that is filled with  
9 water. In order to change the angle of attack of the  
10 supercavitating underwater research model, the tow tank must  
11 be drained so as to enable personnel to adjust some of the  
12 mechanical components on the nose assembly. However, this  
13 is a time consuming endeavor because a significant amount of  
14 time is needed to fill and drain the tow tank. What is  
15 needed is an apparatus that that can vary the angle of  
16 attack of the cavitator on a supercavitating underwater  
17 research model while the tow tank is filled with water and  
18 the supercavitating underwater research model is still in  
19 motion. The prior art discloses several moveable nose  
20 assemblies, however, such assemblies are not suitable for  
21 use with supercavitating underwater research models. For  
22 example, Patterson, U.S. Patent No. 3,069,112 discloses a  
23 missile nose assembly that pivots about the missile's  
24 longitudinal axis. Thomson, U.S. Patent No. 4,579,298  
25 discloses a pivotable nose assembly having a plurality of

1 pivoting actuators that are coupled to the nose's base.  
2 Kranz, U.S. Patent No. 4,793,571 discloses a pivotable nose  
3 assembly having a plurality of actuating plungers coupled to  
4 an end plate of the nose. Moskovitz, U.S. Patent No.  
5 discloses a rotatable nose assembly for an aircraft. Becker  
6 et al., U.S. Patent No. 5,631,442 discloses a pivotable  
7 warhead assembly having a plurality of bellows that  
8 cooperate to cause a charge to pivot about a ball joint.  
9 None of these prior art patents disclose an apparatus that  
10 addresses the aforementioned problem of changing the angle  
11 of attack of a supercavitating underwater research model  
12 while such model is in motion and underwater.

13

#### 14 SUMMARY OF THE INVENTION

15 It is therefore an object of the present invention to  
16 provide an apparatus that can efficiently, quickly and  
17 accurately vary the angle of attack of a supercavitating  
18 underwater research model while the research model is in  
19 motion.

20 It is another object of the present invention to  
21 provide an apparatus that can vary the angle of attack of a  
22 supercavitating underwater research model that is  
23 inexpensive to manufacture and implement.

24 It is a further object of the present invention to  
25 provide an apparatus that can vary the angle of attack of a

1   supercavitating underwater research model from a remote  
2   location.

3         Other objects and advantages of the present invention  
4   will be apparent from the ensuing description.

5         Thus, the present invention is directed to an apparatus  
6   for changing the angle of attack of a cavitator on a  
7   supercavitating underwater research model. The apparatus  
8   comprises a nose assembly that has a pivotable cavitator  
9   tilt plate, an actuator rod engaged with the cavitator tilt  
10  plate, and a drive system for driving the actuator rod so as  
11  to tilt the cavitator tilt plate to a desired angle. Power  
12  components are remotely located and accessible to an  
13  operator so as to enable an operator to vary the angle of  
14  the cavitator tilt plate while the supercavitating  
15  underwater research model is in motion.

16         In one aspect, the present invention is directed to an  
17  apparatus for changing the angle of attack of a cavitator on  
18  a supercavitating underwater research model. The apparatus  
19  generally comprises a nose assembly having a pivotable  
20  cavitator tilt plate and a watertight compartment, an  
21  actuator member that is supported by the nose assembly and  
22  has a first distal end movably attached to the cavitator  
23  tilt plate and a second distal end opposite the first distal  
24  end and located within the watertight compartment, and a  
25  drive system positioned in the watertight compartment for

1 axially moving the actuator member in a first direction and  
2 in a second direction that is opposite the first direction.  
3 The drive system has inputs for receiving electrical power  
4 signals that control the drive system to move the actuator  
5 member in a desired direction. The apparatus further  
6 comprises an electrical power system positioned at a remote  
7 location for providing the electrical power signals to the  
8 drive system when the supercavitating underwater research  
9 model is either at standstill or in motion. Thus, the  
10 apparatus of the present invention allows the angle of  
11 attack of the cavitator to be changed even when the tow tank  
12 is filled with water and the supercavitating underwater  
13 research model is submerged therein.

14

#### 15 BRIEF DESCRIPTION OF THE DRAWINGS

16 The foregoing features of the present invention will  
17 become more readily apparent and may be understood by  
18 referring to the following detailed description of an  
19 illustrative embodiment of the present invention, taken in  
20 conjunction with the accompanying drawings, in which:

21 FIG. 1 is a side elevational view, in cross-section, of  
22 a supercavitating underwater research model that utilizes  
23 the apparatus of the present invention;

1        FIG. 2A is a cross-sectional view of a nose assembly in  
2        accordance with one embodiment of the apparatus of the  
3        present invention;

4        FIGS. 2B and 2C illustrate the mechanical operation of  
5        a cavitator tilt plate, a link member, and actuator rod that  
6        are shown in FIG. 2A;

7        FIG. 3 is a diagram illustrating a drive system of the  
8        apparatus of the present invention;

9        FIG. 4 is a side elevational view of a cover plate  
10       shown in FIGS. 1 and 2A;

11       FIG. 5 is a view taken along line 5-5 in FIG. 4;

12       FIG. 6 is a side elevational view of a housing shown in  
13       FIGS. 1 and 2A;

14       FIG. 7 is a view taken along line 7-7 in FIG. 6; and

15       FIG. 8 is a schematic diagram illustrating an  
16       electrical power system that powers the drive system shown  
17       in FIGS. 2A and 3.

18

#### 19        DESCRIPTION OF THE PREFERRED EMBODIMENTS

20        Although the apparatus of the present invention is  
21        configured to be used with a super cavitating underwater  
22        research model, the ensuing description is in terms of the  
23        supercavitating underwater research model being simulated by  
24        other components and structures. Referring to FIG. 1, the  
25        supercavitating underwater research model is simulated by

1 forward shell 10 and aft shell 12. Forward shell 10 is  
2 connected to aft shell 12 to form a simulated super-  
3 cavitating underwater research model 14 (hereinafter "model  
4 14"). Model 14 is supported by sting 16. Aft shell 12  
5 covers sting 16 to simulate the length an actual super-  
6 cavitating underwater research model. Sting 16 is attached  
7 to model 14 by a ball joint assembly 18. The other end of  
8 sting 16 is fastened to a strut (not shown). The apparatus  
9 of the present invention comprises nose assembly 20 which is  
10 sized to partially fit in forward shell 10.

11 Referring to FIGS. 1, 2A, 2B and 2C, there is shown a  
12 cross-sectional view of nose assembly 20. Nose assembly 20  
13 comprises cavitator tilt plate 22 to which cone cavitator 23  
14 is attached. In one embodiment, cone cavitator 23 is  
15 attached to cavitator tilt plate 22 by corrosion-resistant  
16 nuts and bolts (not shown). Cone cavitator 23 is shown in a  
17 neutral position (see FIG. 1). Cavitator tilt plate 22 has  
18 several different mounting-holes 24 for mounting different  
19 types of cone cavitators. Cavitator tilt plate 22 includes  
20 central opening 25 for receiving wiring and cables. Nose  
21 assembly 20 includes link member 26, base plate 27 and  
22 actuator rod 28. Base plate 27 functions as a load bearing  
23 member for actuator rod 28. Link member 26 is pivotally  
24 attached to base plate 27 at pivot pin joint 30A. Cavitator  
25 tilt plate 22 is pivotally attached to link member 26 and



1 actuator rod 28 by pivot pin joints 30B and 30C,  
2 respectively. In one embodiment, pivot pin joints 30A, 30B  
3 and 30C are hinge-style pin joints. The attachment of  
4 cavitator tilt plate 22, link member 26 and actuator rod 28  
5 in this manner reduces stress on actuator rod 28. This is  
6 illustrated in FIGS. 2B and 2C. When cavitator tilt plate  
7 22 is in the neutral position and substantially parallel to  
8 base plate 27, the distance D1 between pivot pin 30B and  
9 reference center line 31 is generally equal to the distance  
10 D2 between pivot pin 30C and reference center line 31. When  
11 actuator rod 28 moves outward so as to pivot cavitator tilt  
12 plate 22, the force created by actuator rod 28 pushing  
13 cavitator plate 22 outward causes link member 26 to pivot  
14 downward about pivot pin 30A. As a result, the distance D1  
15 decreases and pivot pin 30B moves closer to reference center  
16 line 31. However, the distance D2 remains substantially the  
17 same thereby substantially eliminating any stress or strain  
18 on actuator rod 28 or on any of the pivot pins 30A, 30B and  
19 30C.

20 Referring to FIGS. 1 and 2A, nose assembly 20 further  
21 includes deflector 34 which has opening 35 sized for  
22 receiving actuator rod 28. Cavitator tilt plate 22 and link  
23 member 26 are secured to deflector 34 by base plate 27.  
24 Nose assembly 20 includes cover 36 to which deflector 34 is  
25 attached. Cover 36 is described in detail in the ensuing

1 description. Nose assembly 20 further includes plenum ring  
2 38. Plenum ring 38 is attached to housing 62 (described in  
3 the ensuing description) and circumferentially extends about  
4 and is spaced from the cover plate 36 and deflector 34. The  
5 space between plenum ring 38 and cover plate 36 defines  
6 plenum 40 for the collection of gas. The space between  
7 plenum ring 38 and deflector 34 define passage 42 which is  
8 in gaseous communication with plenum 40. Passage 42 is used  
9 to introduce gas into plenum 40. A gas source (not shown),  
10 such as a gas generator, is used to introduce gas into  
11 plenum 40 or into other locations in nose assembly 20 or  
12 model 14 that are in gaseous communication with plenum 40.

13 Referring to FIGS. 2A, 4 and 5, nose assembly 20  
14 includes "O" ring seal members 46 and 48. Seal 46 seals the  
15 connection between cover 36 and housing 62 so as to make  
16 compartment 49 watertight. Seal 48 seals the entrance of  
17 actuator rod 28 into compartment 49. Cover 36 further  
18 includes a hollow extending portion 50A, generally annular  
19 body portion 50B, and end portion 50C. Deflector 34 is  
20 attached to hollow extending portion 50A. Cover 36 also  
21 includes through-hole 51 for receiving actuator rod 28, and  
22 openings 52 for the distribution of wires and cables that  
23 are connected to electronics (not shown) that are mounted on  
24 cavitator tilt plate 22. Cover 36 includes through-holes 53  
25 that extend through cover 36 and are in gaseous

1 communication with plenum 40 and function as gas passages.  
2 Cover 36 further includes openings 54 sized for receiving  
3 fastening screws (not shown). In one embodiment, cover 36  
4 also includes portion 55 that is cut out or notched so as to  
5 provide operational space for actuator rod 28.

6 Referring to FIGS. 2A, 6 and 7, nose assembly 20  
7 includes housing 62. Housing 62 comprises hollow center  
8 portion 63 (shown in phantom in FIG. 6) that is in  
9 communication with opening 64. Hollow center portion 63  
10 cooperates with end portion 50C of cover 36 and seal 46 to  
11 provide watertight compartment 49. Housing 62 has a  
12 plurality of through-holes 65 to allow the passage of wiring  
13 and tubing. Through-holes 65 are aligned with corresponding  
14 through-holes 52 on cover 36. Housing 62 further includes a  
15 plurality of threaded through-holes 66 to which gas lines  
16 are attached. Through-holes 66 are substantially aligned  
17 with corresponding through-holes 53 in cover 36.

18 Referring to FIGS. 2, 3, and 8, the apparatus of the  
19 present invention further includes drive system 70. Drive  
20 system 70 generally comprises motor 72, gear reduction  
21 drive train 74, and lead screw 76. In one embodiment,  
22 motor 72 comprises a 24 volt motor. However, motors  
23 having other suitable voltage ratings can be used as well.  
24 FIG. 8 also shows remotely located power components that  
25 control the operation of drive system 70. These power

1 components are described in the ensuing description.

2 Drive system 70 is engaged with actuator rod 28 and moves

3 actuator rod 28 bi-directionally in an axial direction,

4 indicated by arrow 77 in FIGS. 3 and 8. Specifically,

5 motor 72 drives gear reduction drive train 74. Gear

6 reduction drive train 74 drives lead screw 76 which, in

7 turn, axially moves actuator rod 28. The movement of

8 actuator rod 28 is generally parallel to reference axis

9 78. As a result, actuator rod 28 pivots cavitator tilt

10 plate 22 back and forth in the direction indicated by

11 arrow 80 in FIG. 2A. Drive system 70 further comprises

12 limit switches 82 and 84 that limit the movement of

13 actuator rod 28. Limit switch 82 functions as an "in"

14 limit switch and is normally closed. Limit switch 84

15 functions as an "out" limit switch and is normally open.

16 When either limit switch 82 and 84 is tripped, electrical

17 power to motor 72 is shut off. Drive system 70 includes

18 linear potentiometer 88, the purpose of which is discussed

19 in the ensuing description. Actuator rod 28 includes

20 projecting member 90 that extends from actuator rod 28.

21 As actuator rod 28 nears its inward travel limit,

22 projecting member 90 trips limit switch 82. When switch

23 82 is tripped, electrical power to motor 72 is shut off.

24 As actuator rod 28 nears its outward travel limit,

25 projecting member 90 trips limit switch 84 thereby

1 shutting off the electrical power to motor 72. Linear  
2 potentiometer 88 includes terminals 88A and 88B and slide  
3 89 that is connected to fastening device 92. Fastening  
4 device 92 connects slide 89 of linear potentiometer 88 to  
5 actuator rod 28 so that slide 89 moves along with actuator  
6 rod 28. Linear potentiometer 88 is mounted to housing 62  
7 with any suitable mounting device or technique. Thus,  
8 linear potentiometer 88 senses the position of the  
9 actuator rod 28.

10 Referring to FIGS. 1 and 8, the power components used  
11 to power drive system 70 are not located in compartment 49  
12 but are external to nose assembly 20 and accessible to a  
13 user or operator of model 14. The power components  
14 include switch 100, motor power supply 102, regulated  
15 power supply 104 and volt meter 106. The user or operator  
16 of model 14 can increase or decrease the angle of cone  
17 cavitator 23 by activating switch 100 in the appropriate  
18 manner. Thus, the manner in which switch 100 is activated  
19 determines whether actuator rod 28 moves cavitator tilt  
20 plate 22 outward or retracts cavitator tilt plate 22. In  
21 a preferred embodiment, switch 100 is a momentary double  
22 pole double throw (DPDT) toggle switch. In order to move  
23 actuator rod 28 outward so as to increase the angle of  
24 attack of cone cavitator 23, the operator pushes switch  
25 lever 108 in a first direction. As a result, current

1 travels through one side of switch 100, through limit  
2 switch 82, to motor 72, back to the other side of switch  
3 100 and then back to motor power supply 102. Motor 72  
4 operates in a first operational state until actuator rod  
5 28 nears the end of its outward travel limit and closes  
6 limit switch 84. In order to decrease the angle of cone  
7 cavitator 23, actuator rod 28 must be retracted. The user  
8 or operator accomplishes this by maneuvering switch lever  
9 108 in an opposite direction in order to reverse the  
10 polarity of the voltage applied to motor 72 so that motor  
11 72 operates in a second operational state that is opposite  
12 the first operational state. As a result, current flows  
13 through switch 100, through limit switch 82, through the  
14 other side of switch 100 and then to motor power supply  
15 102. Thus, motor 72 operates in the second operational  
16 state until actuator rod 28 nears the end of its inward  
17 travel limit and limit switch 82 is opened. This  
18 configuration allows the operator to achieve fine  
19 adjustment of the angle of cavitator cone 23. The angle  
20 of cone cavitator 23 is measured via linear potentiometer  
21 88, regulated power supply 104, and volt meter 106.  
22 Regulated power supply 104 provides a voltage to  
23 potentiometer terminals 88A and 88B. The voltage at slide  
24 89 of linear potentiometer 88 is compared to the total  
25 voltage applied to linear potentiometer 88 at terminals

1 88A and 88B. Voltage meter 106 measures the voltage  
2 between slide 89 and ground potential. At any given  
3 moment, the voltage measured between slide 89 and ground  
4 potential corresponds to a particular distance in which  
5 actuator rod 28 has moved. This particular distance  
6 corresponds to a particular angle of cone cavitator 23. A  
7 conversion procedure is used wherein the voltage measured  
8 at slide 89 is converted to a distance (e.g. inches, feet,  
9 centimeters, etc.), which is the distance actuator rod 28  
10 has moved, and this distance is then converted into the  
11 resulting angle of cavitator cone 23. In a preferred  
12 embodiment, drive system 70 is calibrated before any test  
13 data is recorded in order to ensure that the conversion  
14 procedure is updated to reflect any fluctuations in  
15 component performance due to temperature or component  
16 tolerances. In one embodiment, the conversion procedure  
17 can be accomplished with a computer or microprocessor 110  
18 and data recorder 112. In such an embodiment, computer  
19 110 receives the voltage measured at slide 89 from  
20 voltmeter 106 and converts the measured voltage to angle  
21 data that represents the angle of the cone cavitator 23.  
22 The angle data is then outputted into data recorder 112.  
23 In such an embodiment, voltmeter 106 is configured as a  
24 digital voltmeter having a digital output. Cables or  
25 wires 114 are connected between drive system 70 and the

1 remotely located electrical component and thus, are in  
2 contact with the water or fluid in the tow tank. Thus,  
3 cables or wires 114 are preferably moisture resistant or  
4 water-proof. During testing of the present invention,  
5 ball joint assembly 18 (see FIG. 1) allowed model 14 to  
6 pitch and yaw as the angle of cone cavitator 23 was  
7 varied. In an alternate embodiment of the invention, nose  
8 assembly 20 and the associated power components can be  
9 modified to operate as a two-axis system wherein cone  
10 cavitator 23 can be moved along two axes. In such an  
11 alternate embodiment, a second motor and second actuator  
12 rod are used to achieve movement of cone cavitator 23 in  
13 two dimensions. In a further embodiment, an air cylinder  
14 is used in instead of actuator rod 28. In such an  
15 embodiment, a generator is used to introduce pressurized  
16 gas into the air cylinder and plenum 40. The gas bleed-  
17 off from the air cylinder is then fed to plenum 40.

18       The apparatus of the present invention allows the angle  
19 of cone cavitator 23 to be accurately and rapidly set to a  
20 desired angle while model 14 is submerged in water and in  
21 motion. The angle of cone cavitator 23 can be set,  
22 determined and recorded from a remote location while model  
23 14 is in motion thereby eliminating the need to drain the  
24 tow tank. Since the cone cavitator angle can be changed  
25 while model 14 is in motion, the resulting dynamics of the



1 change in attack angle can be observed. Nose assembly 20  
2 has supplemental gas ventilation (i.e. through-holes 53 and  
3 66) for transporting gasses to the front of model 14. The  
4 dimensions of through-holes 53 and 66 can be varied so as to  
5 accommodate different gas flow rates. Ventilation holes not  
6 used are easily blocked by suitable techniques known in the  
7 art. Nose assembly 20 has wire passages to receive  
8 instrumentation cabling, sensors and other instrumentation.  
9 Watertight compartment 49 prevents water damage to such  
10 cabling, sensors and instrumentation as well as other  
11 components of drive system 70. Nose assembly 20 is compact,  
12 can be easily transported, and has flexibility for mounting  
13 many different sensors and load cells.

14       The principles, preferred embodiments and modes of  
15 operation of the present invention have been described in  
16 the foregoing specification. The invention which is  
17 intended to be protected herein should not, however, be  
18 construed as limited to the particular forms disclosed, as  
19 these are to be regarded as illustrative rather than  
20 restrictive. Variations and changes may be made by those  
21 skilled in the art without departing from the spirit of the  
22 invention. Accordingly, the foregoing detailed description  
23 should be considered exemplary in nature and not as limiting  
24 the scope and spirit of the invention as set forth in the  
25 attached claims.

1 Attorney Docket No. 82859

2

3 APPARATUS FOR CHANGING THE ATTACK ANGLE OF A  
4 CAVITATOR ON A SUPERCAVITATING UNDERWATER RESEARCH MODEL

5

6 ABSTRACT OF THE DISCLOSURE

7 An apparatus for changing the angle of attack of a cavitator  
8 on a supercavitating underwater research model. The apparatus  
9 has a nose assembly that has a pivotable cavitator tilt plate, an  
10 actuator member and a drive system engaged with the actuator  
11 member to drive the actuator member so as to tilt the cavitator  
12 tilt plate to a desired angle. Power components are remotely  
13 located and accessible to an operator so as to enable an operator  
14 to vary the angle of the cavitator tilt plate while the  
15 supercavitating underwater research model is underwater and in  
16 motion.

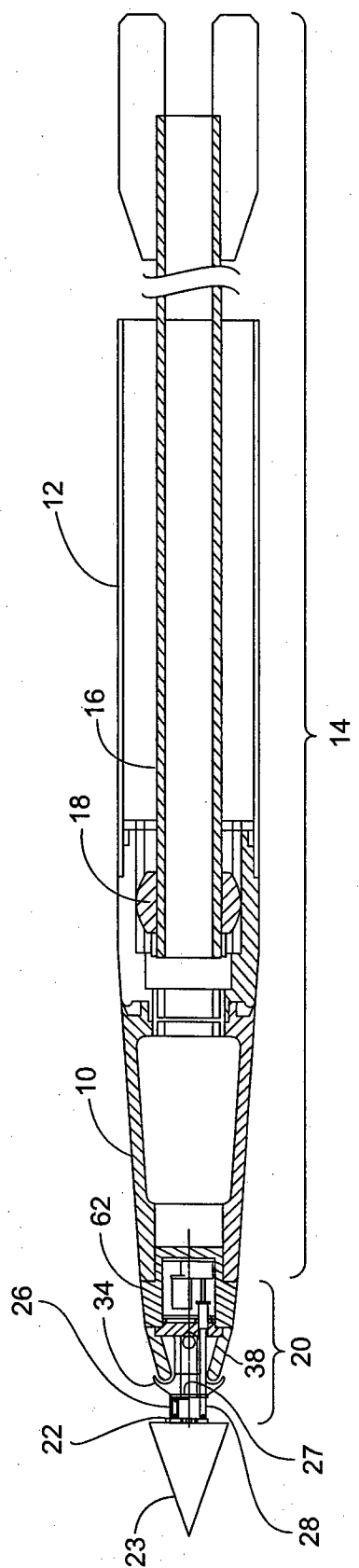


Fig. 1

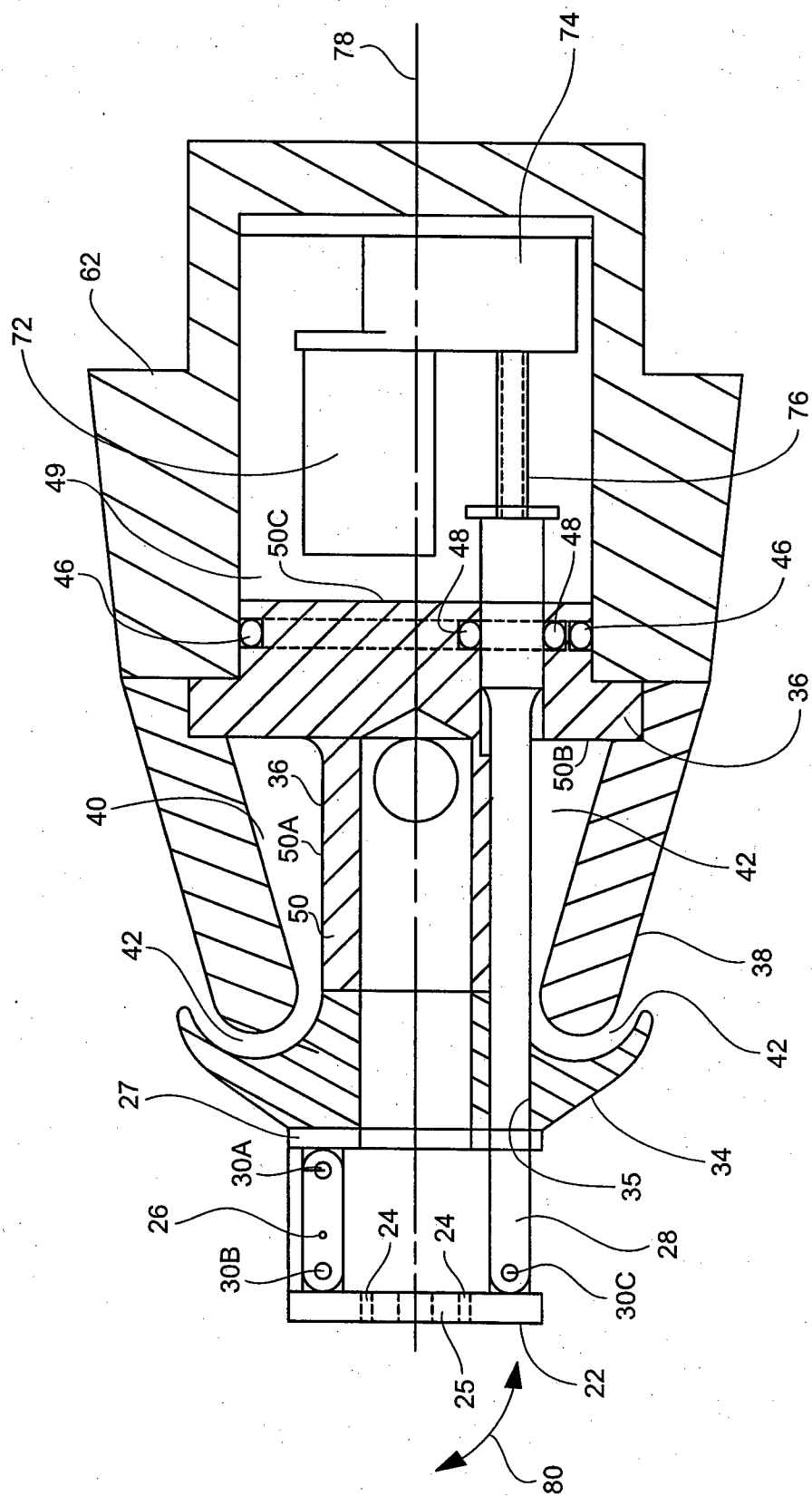


Fig. 2A

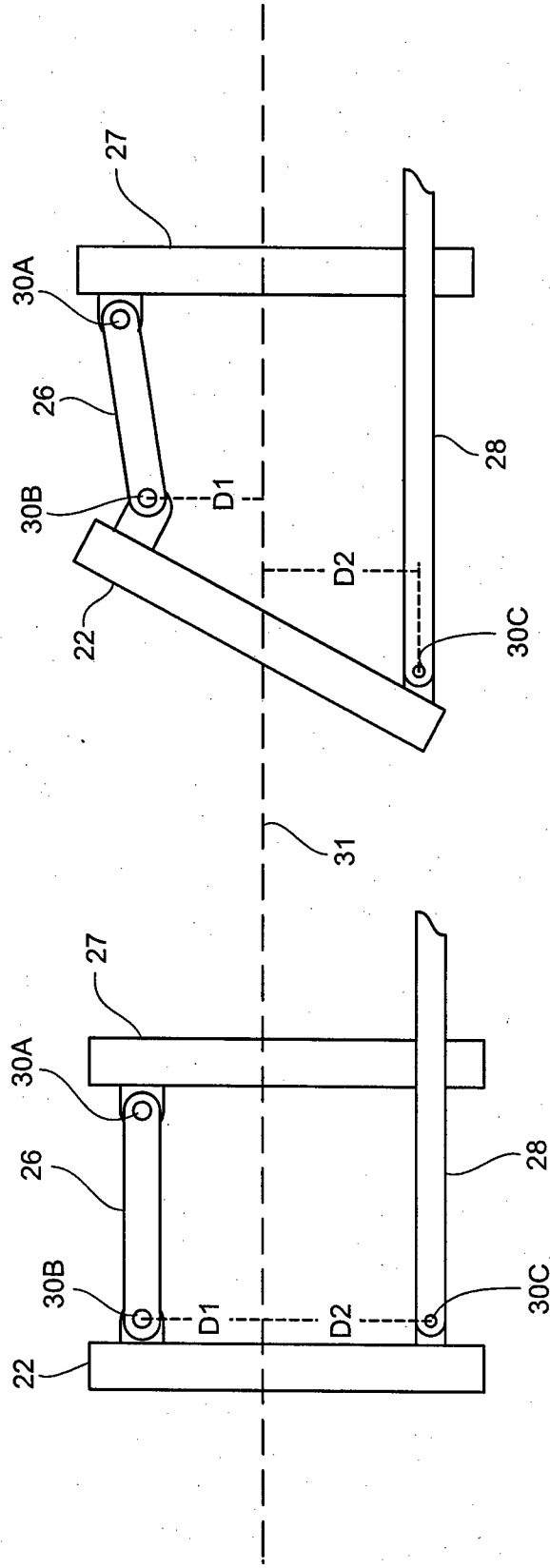


Fig. 2B

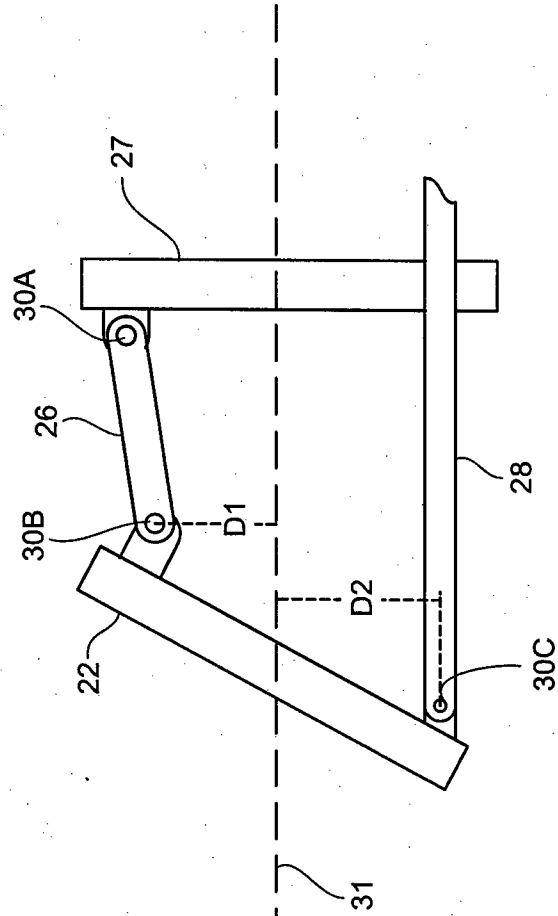


Fig. 2C

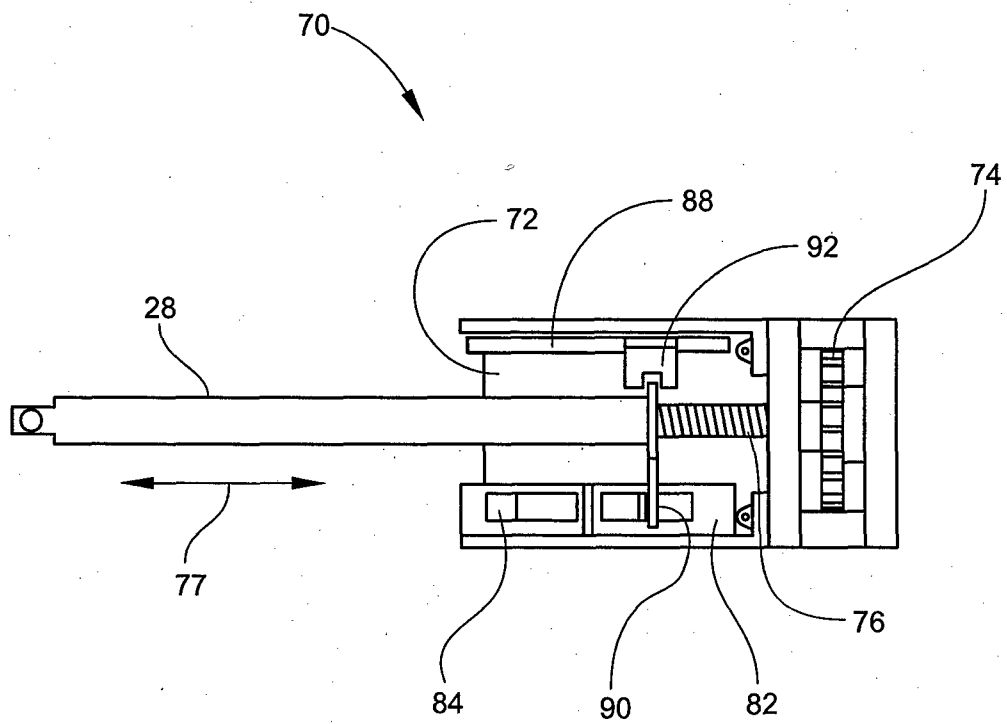


Fig. 3

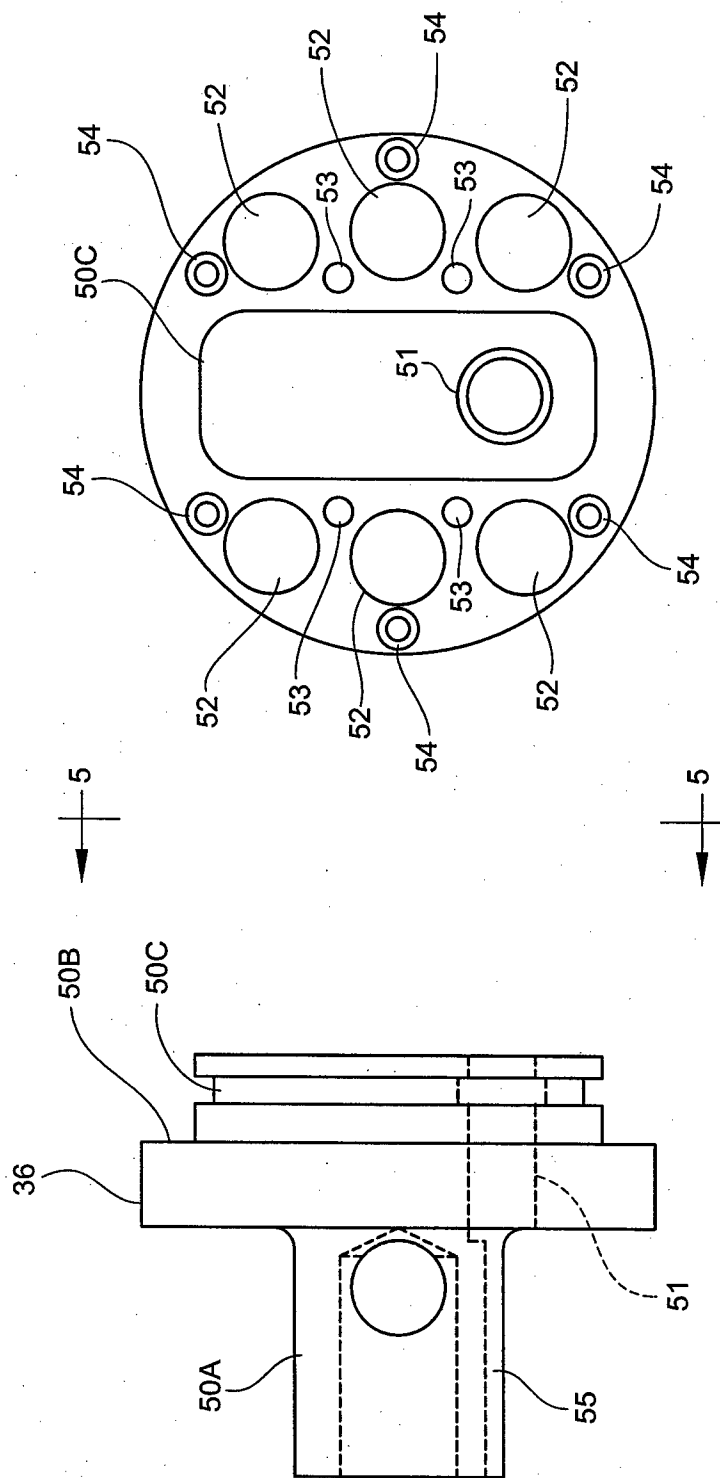


Fig. 4

Fig. 5

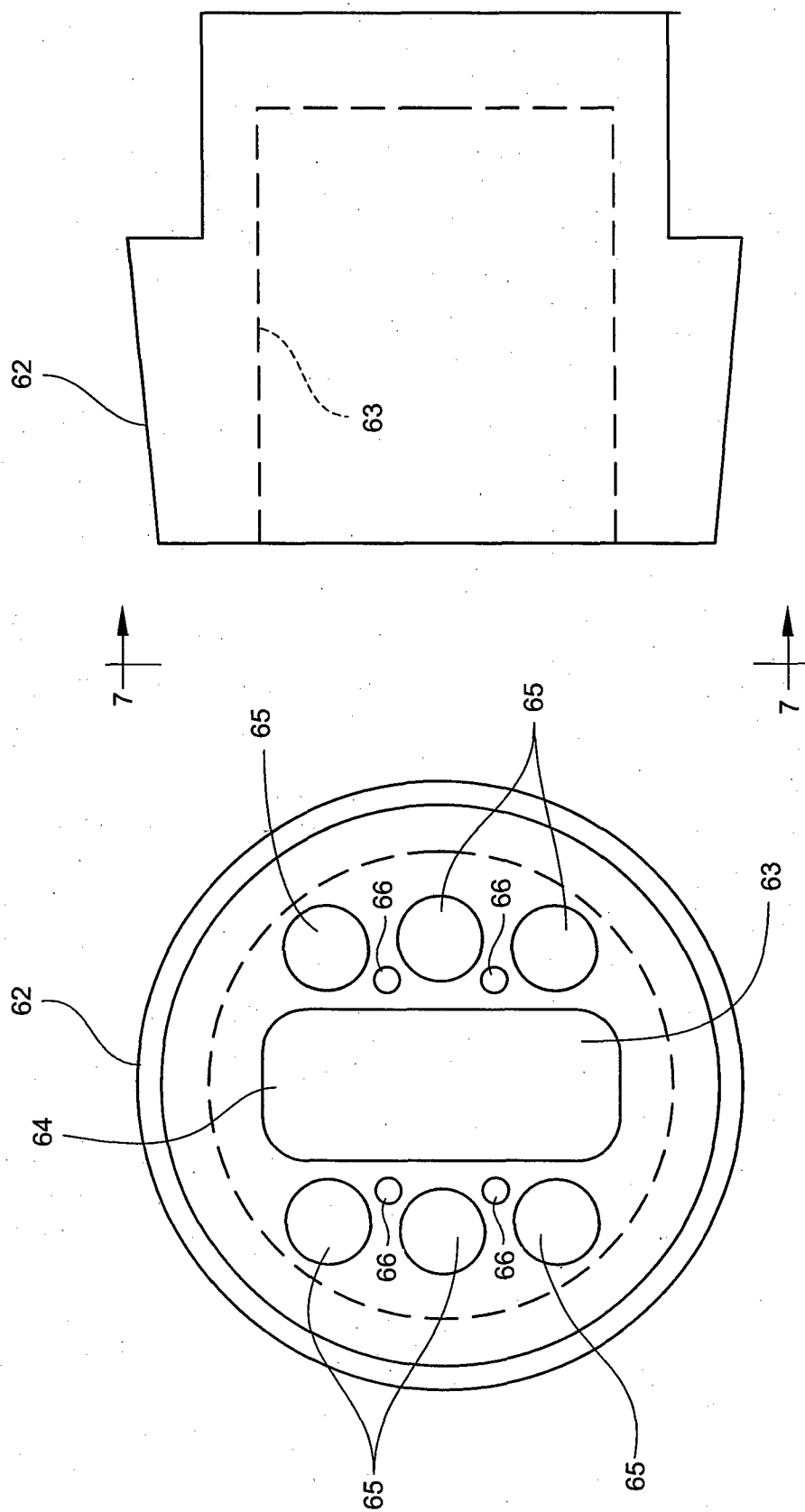


Fig. 6

Fig. 7



